# The Metallicity of the Local IGM from the HST/STIS Spectrum of 3C273

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**Abstract.** We present a preliminary study of the metallicity of low-redshift Lyman alpha absorbers from the HST/STIS spectrum of 3C273. Using a pixel-based shift-and-coadd technique, we compare observations to carefully-constructed mock quasar spectra from a cosmological hydrodynamic simulation. We place an upper limit of $[C/H]_\odot < -1.7$ at $> 90\%$ confidence using two Ly$\alpha$ absorbers with $N_{\rm HI} > 10^{14}{\rm cm}^{-2}$, from the fact that we see no absorption near the expected CIV positions, whereas the artificial spectra predict significant absorption. We test whether this result is sensitive to the assumed shape of the photoionizing background, but find little difference in our results for a Haardt & Madau (quasar-based) flux spectrum or a softer one. With only two absorbers, the sample is still small, but upcoming observations should increase our sample size and provide greater sensitivity.

## 1 Introduction

Weak Lyman alpha (Ly$\alpha$) absorbers that are now detectable in HST/STIS quasar spectra are predicted to arise in diffuse non-equilibrium large-scale structures, analogous to high-redshift forest absorbers[1]; this has been preliminarily confirmed by first comparisons of the statistical properties of Ly$\alpha$ absorbers with simulations[2]. At high redshift, absorbers with $N_{\rm HI} \approx 10^{14.5}{\rm cm}^{-2}$ are already enriched to a level of $[C/H]_\odot \approx -2.5$[3][4]. It is of great interest to study similar absorbers at low redshift, to determine the rate at which metals have been injected into the IGM since $z \sim 3$. The results have implications for understanding early galaxy formation, associated blowout, and winds.

To study absorbers equivalent to $N_{\rm HI} \approx 10^{14.5}{\rm cm}^{-2}$ at $z = 3$ requires one to examine absorbers with $N_{\rm HI} \approx 10^{13}{\rm cm}^{-2}$ at $z \approx 0$[1]. Unfortunately, since the sensitivity of HST/STIS spectra are now only approaching Keck/HIRES and VLT/UVES, it will be very difficult to detect metals in these systems unless the present day metallicity is much higher. This appears unlikely, since the metallicity measured from archival HST/FOS spectra is $[C/H]_\odot = -1.6$ for significantly stronger absorbers[5] (equivalent width $W_r = 0.45 - 0.75$Å, corresponding very roughly to $N_{\rm HI} > 10^{15}{\rm cm}^{-2}$), and simulations predict that less dense gas (i.e. weaker absorbers) has lower metallicity[6].

So instead, here we use stronger absorbers ($N_{\rm HI} > 10^{14}{\rm cm}^{-2}$) to make a first attempt at constraining the local IGM metallicity from the HST/STIS spectrum of 3C273. If anything, the metallicity in these systems is expected to be higher than $[{\rm C/H}]_\odot = -2.5$, since they are denser (overdensities $\approx 30-50$[1]) and there has been significant time since $z \sim 3$ to enrich these regions further. We use C IV absorption to trace the metallicity, as it is expected to be the strongest metal line redwards of Ly$\alpha$ arising from diffuse IGM gas.

## 2 Data and Simulations

The observations of 3C273 are discussed by Heap et al. in these proceedings. They were taken using HST/STIS's E140M grating, yielding 3 km/s pixels with 2.2 pixels per resolution element. The average S/N was 13 per pixel in the C IV region for 3C273, with a C IV redshift coverage of $\Delta z = 0.097$.

We compare to mock 3C273 quasar spectra drawn from a cosmological hydrodynamic simulation[2]. To model metal absorption, we add a uniform metallicity to the gas, and compute the C IV absorption using CLOUDY, taking the local density and temperature of gas from the simulation[4] and assuming an ionizing background predicted from quasars[7] (hereafter HM), with its amplitude set by matching the H I column density distribution amplitude[2].

3C273 has some fortunate advantages for the study of metal absorption. In addition to being at a redshift ($z_{\rm em} = 0.155$) that provides good coverage for both Ly$\alpha$ and C IV, and being the brightest nearby quasar, it also has two (apparently intergalactic) Ly$\alpha$ absorbers wih $N_{\rm HI} > 10^{14}{\rm cm}^{-2}$, where we would expect less than one[2].

## 3 Results

There are no intergalactic C IV absorbers detected as individual lines in the spectrum of 3C273. Thus we must rely on stacking techniques to improve our sensitivity. It has been noted that stacking suffers from the caveat that C IV and Ly$\alpha$ absorbers can be offset by $\sim 10$ km/s or more, so a coadded C IV "feature" will appear broadened[8]. This can result in an inaccurate estimate of the C IV/H I ratio if not interpreted correctly. The reason for this offset is that the ionization conditions of C IV and H I do not exactly match, so when one probes through a filament, the maximum H I absorption will not necessarily be coincident with that of C IV. The simulations used here reproduce this effect, since the ionization structure is computed locally across each absorbing structure. Thus it is important to use simulations to interpret stacked spectra.

Our procedure is as follows: We identify each Ly$\alpha$ absorber with $N_{\rm HI} > 10^{14}{\rm cm}^{-2}$; 3C273 has two such Ly$\alpha$ absorbers at $\lambda = 1219.77, 1296.57$Å. We examine the pixels at associated C IV(1548.2Å) within $\pm 20$ km/s of the Ly$\alpha$

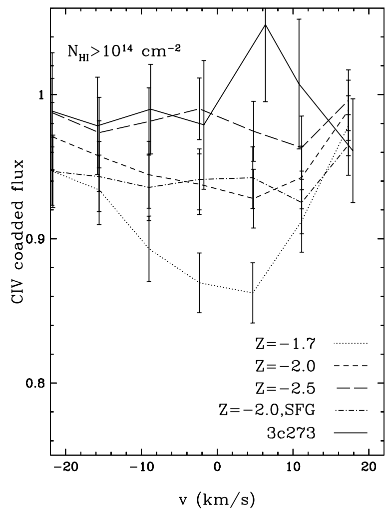


Figure 1: Pixel-by-pixel coaddition within $\pm 20$ km/s centered on Ly$\alpha$ absorbers with $N_{\rm HI} > 10^{14}$cm$^{-2}$. Solid line shows result from 3C273, with other lines show results from artificial spectra with uniform metallicity added as indicated.

absorber velocity, and bin those fluxes (constrained by the doublet flux) in velocity space. Our Voigt profile-fit column densities for these absorbers are consistent with results from a FUSE+GHRS analysis [10].

The solid line in Figure 1 shows the result of this procedure for 3C273, while other lines show the result of varying the metallicity in the artificial spectra from $[{\rm C/H}]_\odot = -1.7 \rightarrow -2.5$. The two absorbers in 3C273 show no absorption at the expected CIV position. For $[{\rm C/H}]_\odot = -1.7$, a comparison of the mean flux decrement within $\pm 20$ km/s shows this metallicity is ruled out at $> 2\sigma$ level. Also, a K-S test of the (pre-binned) flux distribution finds a 2.6% probability that the simulated and observed fluxes are drawn from the same sample. The observed and simulated samples are formally consistent for $[{\rm C/H}]_\odot = -2.5$, and discrepant by $\approx 1.5\sigma$ for $[{\rm C/H}]_\odot = -2.0$. Thus we quote a $2\sigma$ upper limit of $[{\rm C/H}]_\odot < -1.7$ for these two absorbers.

Note that the coadded CIV absorption from the artificial spectra is significantly broader than one would expect for individual CIV lines, reflecting the aforementioned offsets in the CIV and Ly$\alpha$ absorption. The absorption is also asymmetric, likely reflecting small number statistics (8 simulated absorbers).

The greatest uncertainty in this calculation is the assumption of shape and amplitude of the ionizing flux. The amplitude is reasonably well-constrained at the Lyman limit, but altering the shape can change the CIV photoionization rate significantly. We have assumed a $J_\nu$ shape taken from quasars by HM, but star forming galaxies may provide a significant contribution to the local flux[9].

In order to test this, we generate a "toy model" star forming galaxy spectrum, where we simply multiply the HM spectrum by $\nu^{-2}$, keeping $\Gamma_{\rm HI}$ fixed. The result for this ionizing spectrum is shown as the dot-dashed line in Figure 1 for $[\mathrm{C/H}]_\odot = -2.0$. In fact, changing the spectrum has little effect on the predicted C IV abundance. This somewhat surprising result arises because of a coincidence in the ionization fraction behavior for the density range probed by these absorbers; for weaker absorbers, considerably *more* C IV is predicted.

Our metallicity constraint could be incorrect if there was chance coincident absorption at the C IV position in the 3C273 spectrum. However, the fact that no absorption is seen at all indicates that this is not occuring.

While there are only two absorber in this spectrum with $N_{\rm HI} > 10^{14}\mathrm{cm}^{-2}$, we could attempt to lower the column density threshold to include more lines and improve statistics. However, reducing even to $N_{\rm HI} = 10^{13.5}\mathrm{cm}^{-2}$ significantly weakens the result, because the simulations predict many more pixels with little or no C IV absorption. In this case, the $\approx 2\sigma$ limit is $[\mathrm{C/H}]_\odot < -1.3$.

## 4 Summary and Discussion

We have placed a preliminary upper limit on the metallicity in filamentary large-scale structure (overdensity $\approx 30-50$) using two absorbers with $N_{\rm HI} > 10^{14}\mathrm{cm}^{-2}$ in the HST/STIS spectrum of 3C273. Using cosmological hydrodynamic simulations to calibrate the pixel-based stacking technique, we find $[\mathrm{C/H}]_\odot < -1.7$ at greater than 90% confidence level, with only weak sensitivity to the assumed ionizing background shape.

If our result holds up with upcoming larger, more sensitive samples (i.e. the two 3C273 absorbers do not have atypically low metallicity), this would suggest that the metallicity of the diffuse IGM has not increased significantly since $z \sim 3$. The implication is that the enrichment of the IGM occured predominantly at $z >> 3$, a fact that may constrain wind and ejection models from high redshift galaxies (e.g. Ferrara, these proceedings), and help interpret O VI observations in the local IGM (Tripp et al., these proceedings).

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